DOCUMENT RESUME

ED 151 672 CG 012 272

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TITLE A Profile of the Cognitive Development of Freshman Engineering Students.
SPONS AGENCY Fund for the Improvement of Postsecondary Education (DHEW), Washington, D.C.
PUB DATE 30 Aug 77
NOTE 13p.; Paper presented at the Annual Convention of the American Psychological Association (San Francisco, California, August 26-30, 1977)

EDRS PRICE MF-$0.83 HC-$1.67 Plus Postage.
DESCRIPTORS *Cognitive Development; *College Freshmen; Developmental Psychology; *Developmental Stages; *Diagnostic Tests; Engineers; Higher Education; *Logical Thinking; *Problem Solving; Research Projects

ABSTRACT

American college students are highly diverse with respect to formal intellectual development. This diversity can present educators with a difficult challenge, especially in fields that depend heavily on mathematics. The Cognitive Development Project at the University of Massachusetts is an attempt to foster the development of formal operational problem-solving skills among engineering students. As a first step in the program a written diagnostic test was given to the 400 students of the entering Fall 1976 freshman class. Areas of formal logic were: ratio reasoning; separation and control of variables; if-then reasoning; and transformations of frame of reference. This paper presents a profile of the freshman Engineering class as it appeared in September 1976. In addition to the Piagetian measures already mentioned, conventional indicators of scholastic performance are included (S.A.T. scores, first semester grade point average, and level of mathematical skill). Correlations between these various measures are presented and discussed. These statistics provide a framework for consideration of the following two questions: (1) To what extent is formal operational ability related to our traditional concept of schclastic aptitude? (2) Do formal skills tend to be developed in isolated context areas or do they generally extend to all areas? (Author)

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A PROFILE OF THE COGNITIVE DEVELOPMENT OF FRESHMAN ENGINEERING STUDENTS

Presented at the session on

Enhancing the Cognitive Development of College Students: Instruction and Assessment

American Psychological Association Convention

San Francisco Aug. 30, 1977

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*The Cognitive Development Project is supported by a grant from the Fund for Improvement of Post-secondary Education, Department H.E.W.

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ABSTRACT

Studies by Renner (1973, 1976) and Tomlinson-Keasey (1972) indicate that American college students are highly diverse with respect to formal intellectual development. Karplus, Karplus, Formisano and Paulsen (1975) have shown that within the pre-college population (13 to 15 years old) the same range of development exists in seven of the Western industrialized countries. This diversity can present educators with a difficult challenge especially in fields that depend heavily on mathematics. The Cognitive Development Project at the University of Massachusetts is an attempt to foster the development of formal operational problem-solving skills among engineering students during their first three semesters.

As a first step in the program a written diagnostic test was given to the 400 students of the entering Fall 1976 freshman class. Four areas of formal logic were measured: ratio reasoning; separation and control of variables; if...then... reasoning; and transformations of frame of reference. In addition to these Piagetian measures students were also given a battery of tests designed by McBer and Company which measured: achievement motivation; self-definition/cognitive initiative; learning style; critical thinking skill; and ability to analyze arguments.

The formal operations diagnostic was used to select students for a series of special developmental courses. Each course stressed one specific aspect of formal thought, for example ratio reasoning, and emphasized its value as a problem-solving heuristic. Following these courses students will take a two-semester physics sequence in which the use of formal reasoning will be explicitly required. (Aspects of the physics sequence are described in a paper at this symposium by Robert Gray.)

This paper will present a profile of the freshman Engineering class as it appeared in September 1976. In addition to the Piagetian and McBer measures already mentioned, conventional indicators of scholastic performance are included (S.A.T. scores, first semester grade point average, and level of mathematical skill). Correlations between these various measures are presented and discussed. These statistics provide a framework for consideration of the following two questions. To what extent is formal operational ability related to our traditional concept of scholastic aptitude? Do formal skills tend to be developed in isolated context areas or do they generally extend to all areas? For example, is the ability to transform spatial reference frames related to the ability to analyze arguments (personal points of view)?

Finally some thoughts are offered on the extent to which a college education requires formal thought and on the degree to which it encourages intellectual development.

A Profile of the Cognitive Development

of Freshman Engineering Students

Introduction

For the past two years the Physics Department and the School of Engineering at the University of Massachusetts, Amherst have conducted a Cognitive Development Project; support has been provided by a grant from the Fund for Improvement of Post-secondary Education, Department of H.E.W. A basic assumption of the project is that many college Freshmen are not fully developed in their formal reasoning abilites. This suggests three courses of action: 1) diagnostic testing to determine the formal level of each student; 2) creation of courses designed to raise the level of students' reasoning; 3) modification of existing courses to make them more consistent with student abilities. Although the data presented in this paper is primarily from the diagnostic test, interpretation has been significantly influenced by experience teaching these same students.

Description of Diagnostic Test

At the beginning of the Fall 1976 semester all freshman engineering students were instructed to take a two hour diagnostic exam. The exam was given during the evening and was consequently unpopular with some of the students. The first part of the exam (45 minutes) was a written test of Formal Operations. It included four areas: ratio reasoning; control of variables; if...then...logic; and transformation of reference frame, both spatial and kinematic. Most of the questions in the ratio and control of variable sections were from literature. On the other hand the sections on if...then...logic and frame of reference consisted of new untested items.

Because we expected considerable variability in the time needed to complete the test two difficult mathematical puzzles were added to the end of the exam. These were not scored.

Following the "Piaget" test students took a one-hour battery of cognitive tests compiles by the McBer Co. There were two forms:

1) learning styles inventory (10 min.), picture-story (30 min.), Analysis of Argument (20 min.).
2) learning styles inventory, picture-story, Test of Thematic Analysis (20 min.).

These tests required the students to write short essays and about 20% of the students indicated displeasure with the tests. Apparently these students felt that the tests measured writing skill and that they were therefore irrelevant.

The learning styles inventory is a brief self-report questionnaire using multiple choice responses. The picture-story test requires students to write brief stories telling what they believe is happening in certain photographs of people engaged in some activity. These essays are scored in several different ways to yield measures such as achievement motivation and cognitive self-definition. The Analysis of Argument has students read a brief article on a controversial subject. They then must write one essay in support of the author and one in opposition. The test is scored according to the logical consistency employed in both essays and the degree to which students demonstrate an ability to understand two points of view. The test of Thematic Analysis presents students with two groups of short essays and asks students to compare and contrast the groups. The test is scored according to whether students compare superficial factors or stylistic and thematic components.

Measures of Test Validity

It is generally believed that written tests cannot effectively measure a student's level of operational development. Our objective, however, was not to determine with precision the full formal reasoning ability of each student; rather we merely needed a rough indication. Several of the test items have already been correlated with classical Piagetian interviews; see Renner (1977) and Lawson (1977). Typically Pearson product-movement coefficients range from .6 to .8; but Lawson indicates that when test reliability is taken into account correlations could be as high as .9.
In addition to the above statistical indicators of test validity some subjective measures are available. Special attention was given to students who were diagnosed as pre-formal and the experience of teaching these students tended to confirm the predictions of the test. On the other hand several students who tested as formal or transitional performed as concrete operational in many class room situations.

Table 1 presents correlation coefficients between the four sections of the test. It can be seen that these correlations are high and that the test does appear to measure some common construct. On the basis of face validity, correlation to Piagetian interview and consistency with teaching experience it seems likely that the measured construct is closely related to Piaget's notion of formal reasoning. Obviously a good deal more data needs to be collected before a thoroughly convincing case can be made for the validity of the test.

Evidence for the validity of the McBer cognitive skills battery is contained in Higher Education Consortium on Assessment; Twelve-month Evaluation.

Correlations Between Components of the "Piaget" Test

N		Ratio	Control Variables	If ... Then ...	Reference Frames
130	Ratio	1.	.66	.84	.53
240	Control of Variables		1.	.88	.83
240	If ... then ... reasoning			1.	.74
240	Frames of reference				1.

Correlations Between the Ratio Components of the "Piaget" Test and Three Other Measures

		SAT V	SAT M	N Power
130	Ratio	.31	.59	.26

Correlations Between the "Piaget" Test and Five Other Measures

		Piaget Test
240	SAT M	0.04
240	SAT V	0.12
130	1st Semester G.P.A.	0.05
130	Analysis of Argument	-0.01
130	Thematic Analysis	-0.10

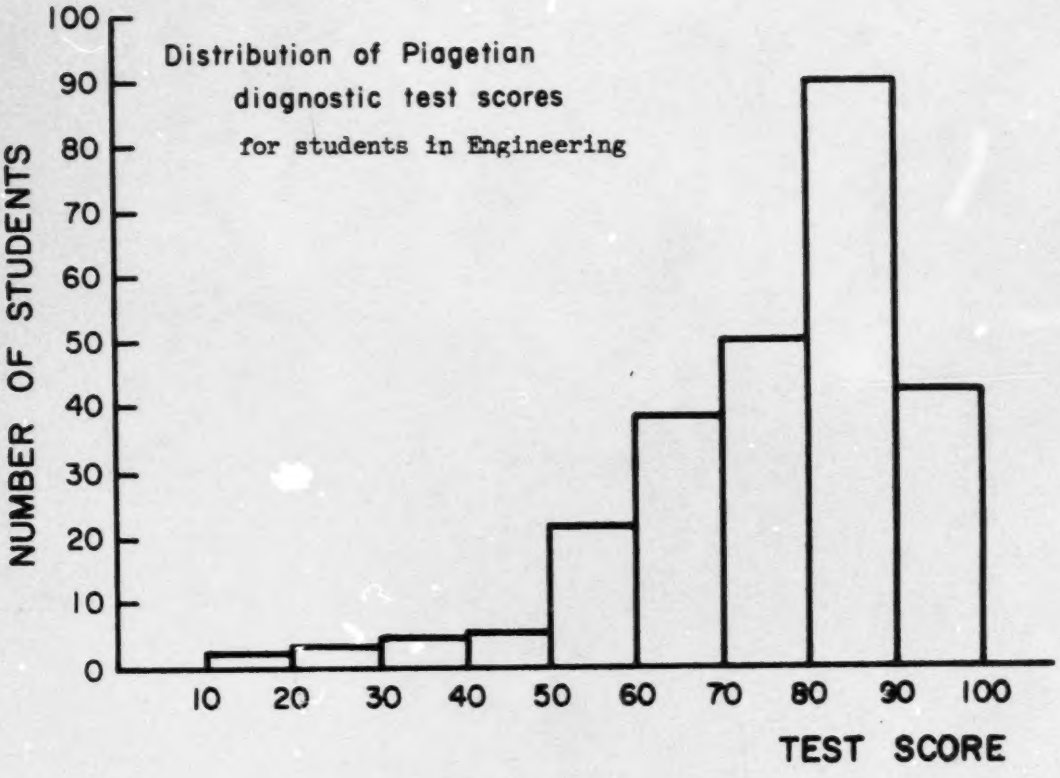
TABLE 1

As in the case of the "Piaget" test, claims of validity are tentative. Some of the McBer measures are designed to identify cognitive skills which correlate with neither grades nor S.A.T. score, but rather with long-term career success. Obviously it is difficult to establish the validity of such measures. However, the face validity of tests such as the Analysis of Argument is convincing especially in the context of work such as Perry (1965).

Test Results[1]

The "Piaget" test indicated that less than 5% of the engineering freshmen were concrete operational. The distribution of test scores for all four types of formal reasoning was highly skewed with modes in the vicinity of 80% correct. These results contrast sharply with studies on non-engineering populations where 25% to 50% of the students are concrete. They suggest that the field of engineering attracts relatively few pre-formal thinkers. Further support of this hypothesis is provided by the Analysis of Argument results which yielded a mean class score of -0.6. This can be compared to the mean of -2.27 obtained at an Ivy League university and means of -3.0 at other colleges. Standard deviations for all samples were close to 2.0. The engineer's performance is surprising, especially in the light of the testing situation and the negative attitudes exhibited towards the test. In other respects the engineers were similar to freshmen at other schools. The mean on the Test of Thematic Analysis was 0.75; this compares with means of 0.40 to 1.22 obtained elsewhere. Self-definition was -3.2 which is average for university freshmen.

[1]Most of the statistical data presented in this paper was prepared by the Institute for Competency Assessment, McBer and Company, 137 Newburry St., Boston, MA 02116.


Distribution of Piagetian
diagnostic test scores
for students in Engineering
NUMBER OF STUDENTS
0
10
20
30
40
50
60
70
80
90
100
10
20
30
40
50
60
70
80
90
100
TEST SCORE

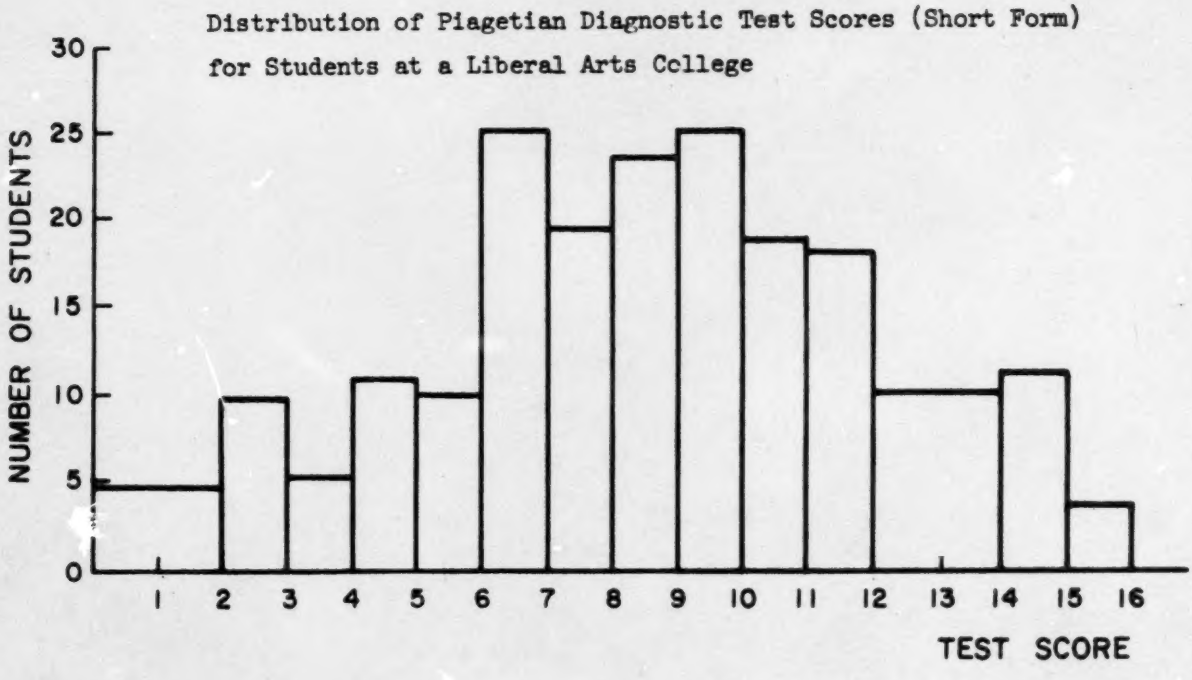

Distribution of Piagetian Diagnostic Test Scores (Short Form)
for Students at a Liberal Arts College
NUMBER OF STUDENTS
0
5
10
15
20
25
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
TEST SCORE

Figure 1

There was no correlation between the "Piaget" test and other measures. In particular, the test was not correlated with first semester grades, S.A.T. or the Analysis of Argument. One exception was the ratio section of the test which did correlate with S.A.T. (.6 math .4 verbal). Although a correlation with math S.A.T. was expected the correlation with verbal S.A.T. is hard to explain.

Conclusions

In several respects engineering freshman score significantly higher on tests of cognitive development than do other freshmen. Two interpretations seem plausible:

1) Science attracts more than an equal share of formal thinkers.

2) Piaget's tests of cognitive development are biased in favor of scientific reasoning.

Two pieces of evidence favor the first hypothesis. Engineers score high on the Analysis of Argument even though it does not appear to be biased towards science or mathematics (This claim is strengthened by the lack of any correlation between scores on the Analysis of Argument and the "Piaget" tests.). Second, if current tests are unfairly biased in favor of scientists then it should be possible to find cognitive measures which favor some other group. So far no such measures have been found.

Within the group of engineering students there are noticable differences in ability to reason formally. These are reflected in high correlations between the four separate sections of the "Piaget" test. However, these differences are not strongly related to scholastic performance.

Some minimal level of formal development is apparently desirable for the study of engineering but grades in engineering courses seem to primarily reflect other skills.

The low correlation between academic performance and formal operational ability is probably due to two factors. One factor is the manner in which students learn material and earn grades. This is most often done by rote and involves very little understanding or reasoning. Faculty have been conditioned to teach and test students in a way that is consistent with rote learning because they have found other methods to be unrewarding. Second, adult reasoning involves a much more complex array of logical and intuitive skills than those described by Piaget's concept of Formal reasoning. The zero correlation between the Analysis of Argument and the frame of reference transformation section of the "Piaget" test indicates that even within the domain of reference frame transformations there are a variety of specific skills. Thus a student with little ability at formal reasoning may nonetheless perform well in many academic and real-life situations.

However, the fact that non-formal thinkers can survive even within a field such as engineering should not be viewed as invalidating the importance of the construct. A society in which a high percentage of adults are non-formal thinkers cannot afford to require formal thought as a prerequisite for success. But this does not mean that society might not be improved if we could increase the number of formal thinkers and then demand that level of analysis in most decisions. Within the field of engineering there are countless examples of failures caused by designers who operated from rote.

Implications

There is little evidence to suggest that formal thinking is necessary or even helpful in acquiring a college education. Correlations between measures of formal reasoning and college grades are generally low. On the other hand students in physical science programs do seem to score significantly higher than other groups on several tests of cognitive development. This evidence is consistent with the claim that science and physics, in particular, is a good vehicle for developing formal reasoning. If this is indeed true, then it would seem that current trends in education are likely to decrease even further the percentage of college students capable of formal thought.

The above conclusion is admittedly speculative but suggests that research on the following questions is of the utmost importance:

1) Is the ability to reason formally as desirable as Piaget's theory would make it appear to be?
2) Should our concept of cognitive development be expanded to include skills not referred to by Piaget?
3) Does the study of physical science enhance formal reasoning rather than merely select for it?
4) If the study of physical science does, in fact, enhance formal reasoning, how can this be used to the advantage of other disciplines?

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